

## AFRL-RX-WP-TM-2013-0229

# INNOVATIVE APPROACH FOR HIGH STRENGTH, HIGH THERMAL CONDUCTIVE COMPOSITE MATERIALS: Data Base

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#### 1.0 SUMMARY

Hybrid matrix (polymer and thermal conductivity filler) pitch fiber composites were developed. Testing was performed on multiple pitch fiber types, from which we were able to down select K6356U pitch fiber with balanced TC and strength properties. A prepreg processing line was created capable of infusing the unidirectional pitch fiber tape. This processing line has the capability to be used with other fiber types as well. Aluminum hybrid matrix composites were manufactured using a resin exfusion process as well as conventional compression molding, so as to compare the two processes. It was found that compression molding outperforms autoclaving in regards to both thermal and mechanical properties.

#### Highlights:

- Increasing the thermal and mechanical properties of aluminum particulate pitch fiber composites over control composites
- Creating a robust prepreg processing line to infuse unidirectional pitch fiber tape that can be used with other fibers...Pan-based carbon or glass
- In-plane TC numbers reaching 25-30 W/m\*K for quasi-isotropic pitch fiber composites
- Transverse TC numbers more than double that of control pitch fiber composites
- Compression molding process outperforms autoclaving in mechanical and thermal properties using the same prepreg material and process conditions (better particle packing behavior)
- Cost per pound of P<sup>2</sup>SI's prepreg material drops by 38%/pound making it a viable alternative to steel or aluminum components. The price to produce P<sub>2</sub>SI's hybrid-aluminum-filled pitch fiber prepreg is: \$88/pound.

## 2.0 DATABASE

Table 1: Autoclaved 0° Flexure Strength and Modulus

	claved 0° Fle								
Material:	K6356U/ 30%	Alum. Fill	ed /862W	Prepreg A	ıtoclaved				
Matrix Content:	62.91	% (w/w)		Comp Dens		1.704	g/cm <sup>3</sup>		
Fiber Volume:	37.10	%		Fiber A Weig		154.0	gsm		
Ply Thickness:	0.0078	inches							
Test Method:	ASTM D790:	0°-Flexure	Strength a	ınd Modulu	s				
Normalization:	Normalized to	50% Fiber	volume						
Test Temper	ature (°F)	R'	Γ	R	Γ	25	0	25	0
Moisture Satu	ıration (%)	0.0	0	0.2	12	0.0	0	0.2	12
Environmental	Conditioning	Dr	у	We	et	Dr	у	We	et
Mechanical	Property	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean MPa	662	491	603	447	445	330	337	250
	(ksi)	(96.0)	(71.2)	(87.4)	(64.8)	(64.5)	(47.9)	(48.9)	(36.3)
	Minimum	637	473	560	416	423	314	325	241
	William	(92.4)	(68.6)	(81.2)	(60.3)	(61.3)	(45.5)	(47.0)	(34.9)
Flexure	Maximum	673	499	657	487	475	353	351	260
Strength $(\sigma_{11})$		(97.6)	(72.4)	(95.3)	(70.6)	(68.9)	(51.2)	(50.9)	(37.7)
8 (11)	Standard	15	11	40	30	23	17	10	7
	Deviation	(2.18)	(1.60)	(5.8)	(4.4)	(3.3)	(2.5)	(1.5)	(1.0)
	MPa (ksi) Number								
	Specimens	5	5	5	5	4	4	5	5
	Mean GPa	90.6	67.2	92.1	68.4	95.0	70.5	63.2	46.9
	(msi)	(13.1)	(9.7)	(13.4)	(9.9)	(13.8)	(10.2)	(9.2)	(6.8)
		88.0	65.3	88.3	65.5	92.0	68.0	55.1	60.4
	Minimum	(12.8)	(9.5)	(12.8)	(9.5)	(13.3)	(9.9)	(8.0)	(8.8)
Flexure	Maximum	94.2	69.9	95.2	70.7	98.0	73.0	81.4	40.9
Modulus		(13.7)	(10.1)	(13.8)	(10.3)	(14.2)	(10.6)	(11.8)	(5.9)
$(\mathbf{E_{11}})$	Standard	2.5	1.8	2.6	1.9	3.3	2.4	11.1	8.2
	Deviation GPa (msi)	(0.4)	(0.3)	(0.4)	(0.3)	(0.5)	(0.3)	(1.6)	(1.2)
	Number Specimens	5	5	5	5	4	4	5	5
	Mean (%)	NA	1.057	NA	0.903	NA	0.775	NA	1.302
	Minimum		0.972		1.150		0.700		0.995
	Maximum		1.112		0.725		0.880		2.047
Peak Strain (E <sub>11)</sub>	Standard Deviation (%)		0.061		0.157		0.076		0.435
	Number Specimens		5		5		5		5

Table 2: Compression Molded 0° Flexure Strength and Modulus

Table 2: Compre	ession Molded 0° Flo	exure Stren	igth and N	Aodulus			
Material:	K6356U / 30% Alum. l	Filled / 862W	/ Compress	ion Molded			
			_				
35.43.00.4	62.91 (1-3)	% (w/w)		G	D 11	1.782(1)	1.834 <b>g/cc</b>
Matrix Content:	,			Composite	Density:	(2) 1.8	
T2*1 X7 1	38.50 (1) 34.40 (2)	%				Ì	
Fiber Volume:	36.60 (3)			Fiber Area	ıl Weight:	154.00	(1-3) <b>gsm</b>
Dl., Th. ! . l.,	0.0072 (1) 0.0084 (2)	inches					
Ply Thickness:	0.0079 (3)						
Test Method:	ASTM D790: 0°-Flexu	re Strength a	nd Modulu	S			
Normalization:	Normalized to 50% Fib	er volume					
Test Tem	perature (°F)	CMP-	1 RT	CMP-	3 RT	CMP	-2 250
	aturation (%)	0.	0	0.2	12	(	0.0
	tal Conditioning	Dr	·y	W		Γ	Pry
	cal Property	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean MPa	735	566	641	469	567	390
	(ksi)	(107)	(82)	(93)	(68)	(82)	(57)
	Minimum	688	530	617	452	525	361
	Minimum	(100)	(77)	(89)	(66)	(76)	(52)
Flexure Strength	Maximum	783	603	658	482	612	421
$(\sigma_{11)}$	Maximum	(114)	(87)	(95)	(70)	(89)	(61)
	Standard	34	26	17	13	40	28
	Deviation MPa	(5)	(4)	(2)	(2)	(6)	(4)
	(ksi)		. ,		` ′	` ′	` '
	Number Specimens	5	5	5	5	4	4
	Mean GPa	104.4	80.4	98.1 (14.2)	71.8	155.7	107.1
	(msi)	(15.1)	(11.7)	> 0.11 (1 <u>.</u> )	(10.4)	(22.6)	(15.5)
	Minimum	100.4	77.3	94.8 (13.7)	69.4	141.3	116.8
Flexure Modulus		(14.6)	(11.2)		(10.1)	(20.5)	(16.9)
(E <sub>11)</sub>	Maximum	107.7	82.9	100.4	73.5	169.8	97.2
( 11)	G. 1 15 14	(15.6)	(12.0)	(14.6)	(10.7)	(24.6)	(14.1)
	Standard Deviation	2.8	2.2	2.2	1.6	13.2	9.1
	GPa (msi)	(0.4)	(0.3)	(0.3)	(0.2)	(1.9)	(1.3)
	Number Specimens	5	5	5	5	4	4
	Mean (%)	NA	0.927	NA	1.111	NA	0.587
	Minimum		0.871		0.910		0.504
Peak Strain	Maximum		0.999		1.295		0.659
( <b>E</b> <sub>11</sub> )	Standard Deviation		0.049		0.127		0.069
	(%)		0.049		0.137		0.009
	Number Specimens		5		5		4
	*			l .			

Table 3: Autoclaved 90° Flexure Strength and Modulus

				and Modu	aius				
Material:	K6356U	/ 30% Alun	n. Filled / 8	02W					
Matrix	62.91	% (w/	/w)						
Content:	02.5	70 (117	•••	Compos	site Densit	ty:	1.70	)4	g/cm <sup>3</sup>
Fiber Volum	e: 37.10	) %		F	'AW:		154.0	00	gsm
Ply Thicknes	o.007	8 inches	S						
Test Method		790: 90°-Fl	lexure Strei	ngth and Mo	dulus				
Normalizatio	n: NA								
Test Temper		R'		R'I		25		25	
Moisture Sat	, ,	0.	0	0.28	83	0.	0	0.28	33
Environ Conditi		Dı	ry	We	et	Dr	у	We	et
Mechanical		Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean MPa	NA	30.4	NA	37.8	NA	36.1	NA	23.6
	(ksi)		(4.4)		(5.5)		(5.2) 25.2		(3.4)
	Minimum	NA	(4.1)	NA	(4.8)	NA	(3.7)	NA	(3.1)
Flexure	Maximum	NA	36.4 (5.3)	NA	43.9 (6.4)	NA	45.2 (6.6)	NA	25.9 (3.8)
Strength σ <sub>11</sub>	Standard Deviation MPa (ksi)	NA	3.4 (0.5)	NA	5.0 (0.7)	NA	7.7 (1.1)	NA	2.2 (0.3)
	Number Specimens	NA	5	NA	5	NA	5	NA	5
	Mean GPa (msi)	NA	4.68 (0.68)	NA	4.98 (0.72)	NA	Noisy	NA	Noisy
	Minimum	NA	4.53 (0.66)	NA	4.83 (0.70)	NA		NA	
Flexure Modulus E <sub>11</sub>	Maximum	NA	4.88 (0.71)	NA	5.20 (0.75)	NA		NA	
Mounts E	Standard Deviation (GPA)	NA	0.13 (0.02)	NA	0.15 (0.02)	NA		NA	
	Number Specimens	5	5	NA	5	NA		NA	
	Mean	NA	0.657	NA	0.841	NA	0.964	NA	Noisy
	Minimum	NA	0.603	NA	0.703	NA	0.710	NA	
D 1 0	Maximum	NA	0.811	NA	0.992	NA	1.230	NA	
Peak Strain ε <sub>11</sub>	Standard Deviation (%)	NA	0.087	NA	0.118	NA	0.224	NA	
	Number Specimens	NA	5	NA	5	NA	5	NA	

Table 4: Comp	ression Molded 90° F							
Material:	K6356U / 30% Alum. Fi	illed / 862W	Compression	on Molded				
Matrix	62.91 (1-3)	% (w/w)		Composite	Donaitza	1.782 (1)	1.834	g/cc
Content:				Composite	Density:	(2) 1.83	9 (3)	
	38.50 (1) 34.40 (2)	%						
Fiber Volume:	36.60 (3)			Fiber A		154.00	(1-3)	gsm
				Weig	ght:	15 1.00	(1 3)	
Ply Thickness:	0.0072 (1) 0.0084 (2)	inches						
I IJ I III EIII EBB	0.0079 (3)							
Test Method:	ASTM D790: 90°-Flexu	re Strength a	nd Modulu	S				
Normalization:	NA				1	•		
	nperature (°F)	CMP-		CMP-			2 250	
	Saturation (%)	0.0		0.2			.0	
	ntal Conditioning	Dr	_	We			ry	
Mechan	ical Property	Normalized	Measured	Normalized	Measured	Normalized		sured
	Mean MPa	NA	33.07	NA	38.90	NA		.37
	(ksi)	1111	(4.80)	1111	(5.64)	1111		68)
	Minimum		30.27		36.63			.98
			(4.39)		(5.31)			48)
Flexure	Maximum		37.45		40.69			.66
Strength (σ <sub>11)</sub>			(5.43)		(5.90)		(3.	87)
	Standard		3.22		1.51		1.	35
	Deviation MPa		(0.47)		(0.22)		(0.	20)
	(ksi)							,
	Number Specimens		5		5			3
	Mean MPa		3936.9		4754.5			94.8
	(ksi)		(570.9)		(689.4)			7.7)
	Minimum		3801.2 (551.2)		4687.1 (679.6)			30.5 6.7)
Flexure			4037.4		4830.3			51.6
Modulus (E <sub>11)</sub>	Maximum		(585.4)		(700.4)			6.4)
	Standard Deviation		87.5		53.9			4.8
	MPa (ksi)		(12.7)		(7.8)			4.0 5.5)
	Number Specimens		5		5			3
	Mean (%)		0.892		0.898		0.8	
	Minimum		0.787		0.853			740
Peak Strain	Maximum		1.011		0.925		0.8	398
( <b>E</b> 11)	Standard Deviation (%)		0.091		0.028		0.0	)85
	Number Specimens		5		5		2	3
	1 tamber opecimens				, i		•	-

Table 5: Autoclaved Short Beam Shear Strength

Table 3. Autociav				,						
Material:	K6356U / 30% A	Alum	. Filled / 8	52W						
<b>Matrix Content:</b>	62.91	%	(w/w)	Con	ipos	ite Den	sity:	1.769	0 <b>g/cm<sup>3</sup></b>	
Fiber Volume:	37.10	%		Fibe	r Aı	real We	ight:	154.	0 <b>gsm</b>	
Ply Thickness:	0.0078	inc	hes							
Test Method:	ASTM D2344: S	hort	Beam She	ar Strength [	$0]_{16}$					
Normalization:	NA	A								
Test Temp	erature (°F)		RT	RT		250	250	C		
Moisture Sa	0.0	0.309	0		0.309					
Environmenta	ll Conditioning		Dry	Wet		Dry	We	et		
Mechanic	al Property		Measured	Measured	Mo	easured	Measu	ıred		
	Mean MPa		42.4	39.4		20.2	20.	0		
	(ksi)		(6.1)	(5.7)	(	(2.9)	(2.9	9)		
	Minimum		40.5	36.3		19.2	17.			
	William		(5.9)	(5.3)	(	(2.8)	(2.5			
SHORT BEAM	Maximum		44.1	41.0		20.5	22.			
SHEAR			(6.4)	(5.9)	(	(3.0)	(3.2	2)		
STRENGTH (S <sub>H</sub> )	Standard		1.3	2.0		0.6	1.9	,		
	Deviation MP	a	(0.2)	(0.3)		(.09)	(0.2			
	(ksi)		(0.2)	(0.3)		(.07)	(0.2	<i>-</i> ,		
	Number		5	5		5	5			
	Specimens					5	1			

Table 6: Compression Molded Short Beam Shear Strength

Table 0. Compi								
Material:	K6356U / 30% Alum. Fil	lled / 862W	Compression	on Molded				
<b>Matrix Content:</b>	62.91 (1-3)	% (w/w)		Composite	Donaitwe	1.782 (1)	1.834	g/cc
Matrix Content:				Composite	e Delisity:	(2) 1.8	339 (3)	
Fiber Volume:	38.50 (1) 34.40 (2)	%						
Fiber volume.	36.60 (3)			Fiber Area	d Weight:	154.	0 (1-3)	gsm
Ply Thickness:	0.0072 (1) 0.0084 (2)							
Try Thickness.	0.0079 (3)							
Test Method:	ASTM D2234: Short Bea	am Shear Pro	perties					
Normalization:	NA							
ID and Test	Temperature (°F)	CMP-	1 RT	CMP-	3 RT	CMP	-2 250	
Moisture	Saturation (%)	0.	0	0.212		(		
	. ,					0.0 Dry		
Environme	ntal Conditioning	Dı		W				
	<u> </u>			Wo Normalized				ured
	ntal Conditioning	Dr Normalized	y	Normalized	et	Normalized	Ory	
	ntal Conditioning nical Property	Dı	y Measured		et Measured	Ι	Ory Meası	05
	ntal Conditioning nical Property Mean MPa (ksi)	Dr Normalized	Measured 47.07	Normalized	Measured 45.77	Normalized	Ory Measi 20.0	05
Mechar	ntal Conditioning nical Property Mean MPa	Dr Normalized	Measured 47.07 (6.83)	Normalized	Measured 45.77 (6.64)	Normalized	Ory	05 01) 66
	ntal Conditioning nical Property Mean MPa (ksi) Minimum	Dr Normalized	Measured 47.07 (6.83) 45.34	Normalized	Measured 45.77 (6.64) 44.35	Normalized	Measi 20.0 (2.9	05 (1) (66 (1)
Mechar	ntal Conditioning nical Property Mean MPa (ksi) Minimum Maximum	Dr Normalized	Measured 47.07 (6.83) 45.34 (6.57)	Normalized	Measured 45.77 (6.64) 44.35 (6.43)	Normalized	Ory Measu 20.0 (2.9 18.0 (2.7	05 01) 66 (1) 25
Mechar SBS Shear	ntal Conditioning nical Property Mean MPa (ksi) Minimum Maximum Standard	Dr Normalized	Measured 47.07 (6.83) 45.34 (6.57) 48.41 (7.02)	Normalized	Measured 45.77 (6.64) 44.35 (6.43) 47.86 (6.94)	Normalized	Dry  Measu 20.0 (2.9 18.0 (2.7 21 (3.0	05 01) 66 (1) 25 08)
Mechar SBS Shear	ntal Conditioning nical Property Mean MPa (ksi) Minimum Maximum	Dr Normalized	Measured 47.07 (6.83) 45.34 (6.57) 48.41 (7.02)	Normalized	Measured 45.77 (6.64) 44.35 (6.43) 47.86 (6.94) 1.63	Normalized	Meass 20.0 (2.9 18.0 (2.7 21.1 (3.0	05 01) 66 (1) 25 08)
Mechar SBS Shear	ntal Conditioning nical Property Mean MPa (ksi) Minimum Maximum Standard	Dr Normalized	Measured 47.07 (6.83) 45.34 (6.57) 48.41 (7.02)	Normalized	Measured 45.77 (6.64) 44.35 (6.43) 47.86 (6.94)	Normalized	Dry  Measu 20.0 (2.9 18.0 (2.7 21 (3.0	05 01) 66 (1) 25 08)

Table 7: Autoclaved Compression Strength

	ciavea coi	npression	Suchgui						
Material:	K6356U	/ 30% Alum	n. Filled / 8	862W					
Matrix Conten	62.91	% (w/w)		Comp Dens		1.769	g/cm <sup>3</sup>		
Fiber Volume		%		Fiber A Weiş		154.0	gsm		
Ply Thickness	0.0078	inches							
Test Method:	ASTM D	695 Compre	ession Stre	ngth [0] <sub>16</sub>					
Normalization	: Normaliz	e to 50% Fi	ber volume	e					
Test Temper	ature (°F)	R	Т	R	Γ	25	0	25	0
Moisture Satu	ration (%)	0	.0	0.3	21	0.0	0	0.32	21
Environn Conditio		D	ry	We	et	Dry		We	et
Mechanical	Duonontr	Normalize	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Froperty	d	Wieasureu	1 (of manzeu	1/1cusureu		112041541244	TOTHIGHZEG	Measurea
	Mean MPa		246	311	231	299	222	157	117
	Mean MPa	331 (48.0) 315	246 (35.7) 234	311 (45.1) 303	231 (33.5) 225	299	222 (32.2) 211	157 (22.8) 135	117 (17.0) 100
Compression	Mean MPa (ksi)	331 (48.0) 315 (45.7) 366	246 (35.7) 234 (33.9) 272	311 (45.1) 303 (43.9) 321	231 (33.5) 225 (32.6) 238	299 (43.4) 285 314	222 (32.2) 211 (30.6) 233	157 (22.8) 135 (19.6) 195	117 (17.0) 100 (14.5) 120
Compression	Mean MPa (ksi) Minimum Maximum	331 (48.0) 315 (45.7)	246 (35.7) 234 (33.9)	311 (45.1) 303 (43.9)	231 (33.5) 225 (32.6)	299 (43.4) 285	222 (32.2) 211 (30.6)	157 (22.8) 135 (19.6)	117 (17.0) 100 (14.5)
Compression Strength σ <sub>11</sub>	Mean MPa (ksi) Minimum	331 (48.0) 315 (45.7) 366	246 (35.7) 234 (33.9) 272	311 (45.1) 303 (43.9) 321	231 (33.5) 225 (32.6) 238	299 (43.4) 285 314	222 (32.2) 211 (30.6) 233	157 (22.8) 135 (19.6) 195	117 (17.0) 100 (14.5) 120
	Mean MPa (ksi) Minimum Maximum Standard	331 (48.0) 315 (45.7) 366 (53.1)	246 (35.7) 234 (33.9) 272 (39.4)	311 (45.1) 303 (43.9) 321 (46.5)	231 (33.5) 225 (32.6) 238 (34.5)	299 (43.4) 285 314 (45.5)	222 (32.2) 211 (30.6) 233 (33.8)	157 (22.8) 135 (19.6) 195 (28.3)	117 (17.0) 100 (14.5) 120 (17.4)

Table 8: Compression Molded Compression Strength

Table 6. Compi	ession Moided Comp							
Material:	K6356U / 30% Alum. Fi	lled / 862W	Compression	on Molded				
<b>Matrix Content:</b>	62.91 (1-3)	% (w/w)		Composite	Density:	1.782 (1) (2) 1.8	) 1.834 339 (3)	g/cc
Fiber Volume:	38.50 (1) 34.40 (2) 36.60 (3)	%		Fiber Area	l Weight:	154.	0 (1-3)	gsm
Ply Thickness:	0.0072 (1) 0.0084 (2) 0.0079 (3)	inches						
Test Method:	ASTM D695: Compressi	on Strength	Properties	$[0]_{16}$				
Normalization:	NA							
Test Ten	nperature (°F)	CMP-	1 RT	CMP-	3 RT	CMF	P-2 250	
Moisture	Saturation (%)	0.	0	0.2	12	(	0.0	
Environme	ntal Conditioning	Dr	у	Wet		Ι	Ory	
		Normalized	Measured	Normalized	Measured	Normalized	Meas	ured
	Mean MPa	373.58	287.66	317.36	232.31	275.42	189	.49
	(ksi)	(54.17)	(41.71)	(46.02)	(33.68)	(39.94)	(27.	48)
	Minimum	351.39	270.57	284.69	208.39	272.65	187	.58
	Willillialli	(50.95)	(39.23)	(41.28)	(30.22)	(39.53)	(27.	20)
Compression	Maximum	402.40	309.85	336.53	246.34	278.20	191	.40
Strength (σ <sub>11</sub> )	Maximum	(58.35)	(44.93)	(48.80)	(35.72)	(40.34)	(27.	75)
	Standard	20.22	15.57	19.92	14.58	3.93	2.7	70
	Deviation MPa (ksi)	(2.93)	(2.26)	(2.89)	(2.11)	(0.57)	(0.3	
	Number Specimens	5	5	5	5	2	2	

Table 9: Autoclaved 0° Tensile Strength and Modulus

Table 9. Au					ength and Modulus					
Material:	K	6356U	/ 30% Alum	n. Filled / 8	362W					
<b>Matrix Conte</b>	ent:	62.91	% (w/w)		Composite	Density:	1.845	g/cm <sup>3</sup>		
Fiber Volum	ie:	34.50	%		Fiber A Weig		154.0	gsm		
Ply Thicknes	ss: 0	.0084	inches		,,	,				
Test Method	d: A	STM D	3039: 0-Ter	nsion and l	Modulus [0]	5				
Normalizatio	n: No	ormaliz	ze to 50% fil	er volume	e					
Test Tempe	rature	(°F)	RT O	NLY	R'	Γ	25	0	25	0
<b>Moisture Sat</b>	uratio	n (%)	NA	A	0		0		0	
Environ		l	Dr	V	We	et .	Dr	v	W	et
	Conditioning			_				-		1
Mechanica				Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
		MPa	1645.6	1135.5						
	(k	si)	(238.6)	(164.6)						
	Mini	mum	1549.1	1068.9						
Ultimate			(224.6) 1750.1	(155.0) 1207.6						
Tensile	Maxi	mum	(253.8)	(175.1)						
Strength ( $\sigma_{11}$ )		dard	89.8	61.9						
	MPa	ation (ksi)	(13.0)	(9.0)						
		nber imens	6	6						
	Mean	ı GPa	304.9	210.4						
	(m	si)	(44.2)	(30.5)						
	Mini	mum	286.5	197.7						
m •1			(41.5)	(28.7)						
Tensile Modulus	Maxi	mum	322.6	222.6 (32.3)						
(E <sub>11)</sub>	Ston	dard	(46.8)							
(211)		ation	14.2	9.8						
		(msi)	(2.1)	(1.4)						
	Nun	nber imens	6	6						
	_	ean	NA	0.3562						
		mum	11/1	0.3362						
		mum		0.3920						
Poisson's		dard								
Ratio (V <sub>12)</sub>	Devi	ation		0.0282						
		nber imens		6						
		n (%)	NA	0.53						
	Mini	mum		0.51		_		_		
		mum		0.56						
Peak Strain	Devi	dard ation %)		0.0002						
	Nun	nber imens		6						

Table 10: Autoclaved 90° Tensile Strength and Modulus

			90° Tensile			iuius		1		
Materi	al:	K6356U	/ 30% Alum.	Filled / 86	52W					
Matri		62.91	% (w/w)		<b>.</b>	1	7.620	3		
Conte		27.70	0.4		Density:		7630 <b>g/cm</b>			
Fiber Vol		37.70			FAW:		154.0 <b>gsm</b>			
Ply Thick	mess:	0.0077	inches							
TD 4 3 5 4		A COTTO A L	2020 000		.1 13.6	1 1 [0]				
Test Met			D3039: 90°Te	nsion Strei	ngth and Mo	odulus [O] <sub>10</sub>	)			
Normaliza	ation:	NA								
Test Ten		(OE)	R'	г	R'	 T	25	·	25	0
Moisture	_				0.2		0.		0.20	
	ronme	•			0.2	00	0.	U	0.20	30
	dition		No	ne	W	et	No	ne	Wet	
Mechar			Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
				19.89		17.92		11.15		9.17
	Mea	n (MPa)	NA	(2.88)	NA	(2.60)	NA	(1.62)	NA	(1.33)
	M	nimum		19.88		NA		8.98		8.20
	IVIII	IIIIIIUIII		(2.88)		NA		(1.30)		(1.19)
Tensile	Ma	ximum		19.90		NA		14.35		10.31
Strength				(2.89)		11/1		(2.08)		(1.49)
$(\sigma_{11})$		ındard		0.02		0.0		2.83		1.06
		viation		(0.003)		0.0		(0.41)		(0.15)
	`	MPa) umber								
		ecimens		2		1		3		3
				6.81		7.21		4.38		3.43
	Mea	ın (GPa)	NA	(0.99)	NA	(1.05)	NA	(0.64)	NA	(0.50)
	N.C.	nimum		6.80				4.01		3.68
	IVIII	nimum		(0.99)		NA		(0.58)		(0.53)
Tensile	Ma	ximum		6.82		NA		5.01		3.21
Modulus				(0.99)		11/1		(0.73)		(0.47)
$(E_{11})$		indard		0.01		0.0		0.55		0.23
		viation		(0.002)		0.0		(0.08)		(0.03)
		GPa) umber								
		cimens		2		1		3		3
		<b>A</b> ean	NA	0.021	NA	0.015	NA	0.027	NA	0.0052
	Mi	nimum		0.017		NA		0.021		0.0054
Poisson's	Ma	ximum		0.024		NA		0.038		0.0051
Ratio	Sta	ındard		0.005		0.00		0.009		0.0002
$(\mathbf{v}_{12})$		viation		0.003		0.00		0.007		0.0002
		ımber		2		1		3		3
		ecimens	NT A		NT A		NT A		NT A	
		an (%) nimum	NA	0.280	NA	0.253	NA	(Noisy)	NA	0.409
Peak		nımum ximum		0.229		NA NA				0.386
Strain		xımum ındard								
ε <sub>11)</sub>		muaru ation (%)	)	0.071		0.00				0.028
_ (11)		ımber		_						
		cimens		2		1				3
				•	•		•	•	•	

Table 11: Autoclaved Northrop Grumman Open-Hole Compression Strength

			071111110011	Open-Hoi	e compr	Coolon St	engu.		
Material:	K6356U/3	0% Alum. F	Filled / 862	W Prepreg	Autoclave	ed			
<b>Resin Content:</b>	65.92	% (w/w)		Comp Dens		1.7780	g/cm <sup>3</sup>		
Fiber Volume:	35.10	%		FAV	W:	154.0	gsm		
Ply Thickness:	0.0081	inches							
Test Method:	Northrop G	rumman: Op	en-Hole C	Compression	ı [45, 0, -4	$[5, 90]_{3s}$			
Normalization:	Normalize t	o 50% fiber	volume						
Test Tempera	iture (°F)	75	5	75	5	25	0	25	0
Moisture Satu	ration (%)	0.0	0	0.12	20	0.0	0	0.13	20
Environn Conditio		No	None		et	None		W	et
Mechanical l	Property	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean MPa (ksi)	145 (21)	102 (15)	141 (20)	99 (14)	108 (16)	76 (11)	104 (15)	73 (11)
	MPa								
Open Hole Compression	MPa (ksi)	(21) 140	(15) 98	(20) 130	(14) 91	(16) 93	(11) 65	(15) 100	(11) 75
	MPa (ksi) Minimum	(21) 140 (20) 151	(15) 98 (14) 106	(20) 130 (19) 148	91 (13) 104	(16) 93 (13) 117	(11) 65 (9) 82	(15) 100 (15) 107	(11) 75 (11) 71

Table 12: Autoclaved In-Plane Shear Strength and Modulus

	utoclaved In-Plane Shear Strength and Modulus								
Material:	K6356U / 3	0% Alum. F	illed / 862	W Prepreg,	Autoclave	ed			
Matrix Content:	62.91	% (w/w)		Comp Dens		1.716	g/cm <sup>3</sup>		
Fiber Volume:	32.60	%			Fiber Areal Weight:		gsm		
Ply Thickness:	0.0085	inches							
Test Method:	ASTM D35	18: In-Plane	Shear Str	ength and Modulus [4:		5, -45, -45,	45] <sub>2s</sub>		
Normalization:	NA								
Test Temperature (°F)		R'	Γ	R'	Γ	25	0	25	0
Moisture Satu		N/	A	0.42	29	N/	4	0.42	29
Environn Conditio		Dr	y	Wet		Dry		Wet	
Mechanical 1	Property	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean	NA	35.69	NA	35.14	NA	19.67	NA	20.35
	MPa (ksi)	INA	(5.18)	11/71	(5.10)	11/71	(2.85)	11/71	(2.95)
	Minimum		31.04		32.44		16.24		19.18
			(4.50)		(4.70)		(2.35)		(2.78)
Maximum	Maximum		40.78		37.90		23.88		21.05
Shear Stress	Standard		(5.91)		(5.50)		(3.46)		(3.05)
$( au_{12)}$	<b>Deviation</b>		4.46		1.99		3.11		0.73
	MPa		(0.65)		(0.29)		(0.45)		(0.11)
	(ksi)		(0.03)		(0.2)		(0.13)		(0.11)
	Number		_		4		_		
	Specimens		5		4		5		5
	Mean		3201.7		3090.8		1827.8		1584.1
	MPa (ksi)		(464.2)		(448.2)		(265.0)		(229.7)
	Minimum		NA		2904.5		1623.8		1413.7
			- 1.0		(421.2)		(235.5)		(205.0)
Chord Shear	Maximum		NA		3230.8		1939.2		1706.0
Modulus (G12)	Standard				(468.5)		(281.2)		(247.4)
iviouulus (G12)	<b>Deviation</b>				145.7		126.3		118.1
	MPa		0.0		(21.1)		(18.3)		(17.1)
	(ksi)				, ,		, ,		` ′
	Number Specimens		1		4		5		5
	Mean		NA		NA		13.64		16.17
							(1.98) 11.71		(2.34) 14.69
Shear Stress at	Minimum						(1.70)		(2.13)
5% Shear							17.54		17.46
Strain $(\tau_{12})$	Maximum						(2.54)		(2.53)
(if applicable)	Standard						2.35		1.17
	Deviation						(0.34)		(0.17)
	Number						5		5
	<b>Specimens</b>						3		3

Table 13: Autoclaved Compression after Impact Strength

14010 13. 1140	toclaved Compression after Impact Strength									
Material:	K6356U/3	0% Alum. I	Filled / 862	W Prepreg,	Autoclave	ed				
								•		
Matrix	65.92	% (w/w)		Comp	osite	1 777	g/cm <sup>3</sup>			
Content:				Dens		1.775	8			
Fiber Volume:	35.50	%		Fiber Areal Weight:		147.0	%			
Ply Thickness:	0.0078	inches								
·		•								
Test Method:	ASTM D71	37 Compres	sion after	Impact Stre	ngth [45, 0	$[0, -45, 90]_{3s}$				
Normalization:	Normalize t			•						
Test Tempera	Test Temperature (°F)		DRY-CONTROL- RT		WET-CONTROL- RT		Impacted-DRY-RT		Impacted-WET-RT	
Moisture Satu	ration (%)	0.	0	0.202		0.0		0.20	02	
Environn Conditio		Dr	У	Wet		Dry		Wet		
Mechanical 1	Property	Normalized	Measured	Normalized	Measured	Normalized	Measured	NT 11 1	Measured	
		11011111111111111	measurea	1 tol manzeu	Micasurcu	Hormanzeu	Measureu	Normalized	Measured	
	Mean MPa (ksi)	148.57 (21.54)	105.48 (15.29)	159.21 (23.09)	113.04 (16.39)	135.34 (19.62)	96.09 (13.93)	128.33 18.61)	91.11 (13.21)	
	MPa	148.57	105.48	159.21	113.04	135.34	96.09	128.33	91.11	
Compression	MPa (ksi)	148.57 (21.54)	105.48 (15.29)	159.21 (23.09)	113.04 (16.39)	135.34 (19.62)	96.09 (13.93)	128.33 18.61)	91.11 (13.21)	
Compression after Impact Strength (σ <sub>11)</sub>	MPa (ksi) Minimum	148.57 (21.54) NA	105.48 (15.29) NA	159.21 (23.09) NA	113.04 (16.39) NA	135.34 (19.62) NA	96.09 (13.93) NA	128.33 18.61) NA	91.11 (13.21) NA	

Table 14: Autoclaved Transverse and In-Plane Thermal Conductivity

1 4010 1 1. 7 141	utoclaved Transverse and in-Frane Thermal Conductivity								
Material:	K6356U/3	0% Alum. F	filled / 862	W Prepreg,	Autoclave	ed			
<b>Resin Content:</b>	65.92	% (w/w)		Composite Density:		1.7780	g/cm <sup>3</sup>		
Fiber Volume:	35.10	%		Fiber . Weig		154.0	gsm		
Ply Thickness:	0.0081	inches							
Test Method:	P2SI's Tran [45, 0, -45,	90] <sub>3s</sub>		nne (IP) The	ermal Cond	luctivity Pro	operties		
Normalization:	Normalize t	o 50% fiber	volume						
Test Tempera	nture (°F)	RT-DR	Y-TT	RT-WET-TT		RT-DRY-IP		RT-WET-IP	
Moisture Satu		0.0	)	0.364		0.0		0.30	64
Environn Conditio		None		Wet		None		Wet	
Thermal Pi	roperty	Normalized	Measured	Normalized	Measured	Normalized	Measured	Normalized	Measured
	Mean (W/m*K)	1.603	1.125	1.815	1.274	28.623	20.093	25.218	17.703
	Minimum	1.503	1.055	NA	NA	26.093	18.317	21.705	15.237
Thermal	Maximum	1.702	1.195	NA	NA	31.151	21.868	28.732	20.170
Conductivity (W/m*K)	Standard Deviation (W/m*K)	0.141	0.099	NA	NA	3.577	2.511	4.969	3.488
	Number Specimens	2	2	1	1	2	2	2	2

Table 15: Compression Molded Transverse RT-DRY Thermal Conductivity

1	ression worded Transverse KT-DKT Thermal Conductivity							
Material:	K6356U / 30% Alum. Fil	lled / 862W ]	Prepreg, Co	ompression N	Molded			
<b>Matrix Content:</b>	62.91 (1-3)	% (w/w)		Composite	Density:	1.782 (1) (2) 1.8	) 1.834 339 (3)	g/cc
Fiber Volume:	38.50 (1) 34.40 (2) 36.60 (3)			Fiber Area	l Weight:	154.0	0 (1-3)	gsm
Ply Thickness:	0.0072 (1) 0.0084 (2) 0.0079 (3)							
Test Method:	P2SI Transverse Therma	l Conductivi	ity Properti	es-RT-DRY	$[0]_{16}$			
Normalization:	NA							
Test Temperature (°F)		CMP-1 (RT)						
Test Ten	nperature (°F)	CMP-1	(RT)	CMP-2	2 (RT)	CMP-	-3 (RT)	
	nperature (°F) Saturation (%)	CMP-1 0.0	` ′	CMP-2 0.	` '		-3 (RT) 0.0	
Moisture	<u> </u>		0		0	(	/	
Moisture Environme	Saturation (%)	0.0	0	0.	0	(	0.0	red
Moisture Environme	Saturation (%) ntal Conditioning	0.0 Dr	0 'y	0. Dr	0 'y	( [	).0 Dry	
Moisture Environme	Saturation (%) ntal Conditioning nal Property	0.0 Dr Normalized	y Measured	0. Dr Normalized	y Measured	( Normalized	).0 Dry Measu	55
Moisture Environme Thern	Saturation (%) ntal Conditioning nal Property Mean (W/m*K)	0.0 Dr Normalized 2.839	Measured 2.186	O. Dr Normalized 3.602	Measured 2.478	Normalized 3.081	Ory Measu 2.25	55
Moisture Environmen Thern Transverse	Saturation (%) ntal Conditioning nal Property Mean (W/m*K) Minimum	0.0 Dr Normalized 2.839 2.816	Measured 2.186 2.168	0. Dr Normalized 3.602 NA	Measured 2.478 NA	Normalized 3.081 NA	Dry  Measu 2.25  NA	55 A

Table 16: Compression Molded RT-WET Transverse Thermal Conductivity

	ression worded K1-WE1 Transverse Thermal Conductivity							
Material:	K6356U / 30% Alum. Fil	lled / 862W ]	Prepreg, Co	ompression N	Molded			
<b>Matrix Content:</b>	62.91 (1-3)	% (w/w)		Composite	Density:		) 1.834 <b>g/cc</b> 339 (3)	
Fiber Volume:	38.50 (1) 34.40 (2) 36.60 (3)			Fiber Area	l Weight:	154.	0 (1-3) <b>gsm</b>	
Ply Thickness:	0.0072 (1) 0.0084 (2) 0.0079 (3)							
Test Method:	P2SI Transverse Therma	l Conductivi	ity Properti	es-RT-WET	$[0]_{16}$			
Normalization:	NA							
Test Temperature (°F)		CMP-1 (RT)						
Test Tell	nperature (°F)	CMP-1	(RT)	CMP-2	2 (RT)	CMP	-3 (RT)	
	nperature (°F) Saturation (%)	CMP-1 0.3		CMP-2			-3 (RT) 363	
Moisture			63		63	0.		
Moisture Environme	Saturation (%)	0.3	63	0.3	63	0.	363	
Moisture Environme	Saturation (%) ntal Conditioning	0.30 WE	63 ET	0.3 WI	63 ET	0. W	363 /ET	
Moisture Environme Thern	Saturation (%) ntal Conditioning nal Property	0.30 WE Normalized	63 ET Measured	0.3 WE Normalized	63 ET Measured	0. W Normalized	363 /ET Measured	
Moisture Environme	Saturation (%) ntal Conditioning nal Property Mean (W/m*K)	0.30 WE Normalized 2.782	63 ET Measured 2.142	0.3 WE Normalized 3.331	63 ET Measured 2.292	0. W Normalized 2.977	363 /ET Measured 2.179	
Moisture Environme Thern Transverse	Saturation (%)  Intal Conditioning  Intal Property  Mean (W/m*K)  Minimum	0.30 WE Normalized 2.782 2.778	63 ET Measured 2.142 2.139	0.3 WI Normalized 3.331 3.167	63 ET Measured 2.292 2.179	0.  Normalized 2.977  NA	363 /ET Measured 2.179 NA	

Table 17: Autoc	laved Fracture Tough	ness by M	ix-Mode	Bending		
Material:	K6356U / 30% Alum. Fil	led / 862W ]	Prepreg, Au	utoclaved		
<b>Matrix Content:</b>	62.90	% (w/w)		Composite	Density:	1.699 <b>g/cc</b>
Fiber Volume:	33.90	%		Fiber Area	l Weight:	147.0 <b>gsm</b>
Ply Thickness:	0.0082	inches				
Test Method:	ASTM D-6671 Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fib Reinforced Polymer Matrix Composites $[0_{16}]$					
Normalization:	NA					
Test Ten	nperature (°F)	R'	Γ	R'	Γ	
	Saturation (%)	0.	0	0.440		
Environmen	ntal Conditioning	DRY		WET		
Mechan	Mechanical Property		Measured	Normalized	Measured	
	Mean (J/m²)	NA	202.95	NA	158.53	
	Minimum		101.51		98.50	
<b>Mode I Fracture</b>	Maximum		349.23		233.18	
Toughness (G <sub>I</sub> )	Standard		108.02		55.87	
	Deviation (J/m2)					
	Number Specimens		4		5	
	Mean (J/m²)	NA	52.49	NA	35.92	
Mode I Fracture	Minimum		26.82		22.12	
Toughness	Maximum		93.99		53.21	
$(G_{\rm I})$	Standard		29.11		12.97	
. 2	Deviation (J/m2)					
	Number Specimens		4		5	
	Mean (%)	NA	20.52	NA	18.41	
Percent Mode II	Minimum		18.49		22.12	
Fracture	Maximum		21.53		53.21	
Toughness (% G <sub>II</sub> )	Standard Deviation (%)		1.38		0.12	
	Number Specimens		4		5	

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12. DISTRIBUTION/AVAILABILITY STATEMEN	т		
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13. SUPPLEMENTARY NOTES			
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see AFRL-RX-WP-TR-2013-0216.	-		
14. ABSTRACT (Maximum 200 words)			
Using the format of Mil Handbook 17,	a complete data base of the results of experime		
	ed on multiple pitch fiber types, from which w		
fiber with balanced TC and strength pro	operties. A prepreg processing line was create	d capable of infusing the unidirectional pitch	

#### 15. SUBJECT TERMS

1. REPORT DATE (DD-MM-YY)

data base report, composite materials, pitch carbon fiber, thermal conductivity, highly graphite fibers, composites

molding outperforms autoclaving in both thermal and mechanical properties.

fiber tape. This processing line has the capability to be used with other fiber types as well. Aluminum-filled composites were manufactured suing a resin exfusion process as well as conventional compression molding. It was found that compression

16. SECURITY CLASSIFICATION OF:			17. LIMITATION	18. NUMBER	19a. NAME OF RESPONSIBLE PERSON (Monitor)
a. REPORT	b. ABSTRACT	c. THIS PAGE	OF ABSTRACT:	OF PAGES	Roger Gerzeski  19b. TELEPHONE NUMBER (Include Area Code) (937) 904-4323
Unclassified	Unclassified	Unclassified	SAR	22	